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13. ABSTRACT (Maximum 200 words) Three fractal stochastic processes were developed and defined. Their statistical properties were derived, and examples were provided. Fractal shot noise (FSN), which is formed when a homogeneous Poisson process is passed through a filter with a power-law decaying impulse response function, was defined. For certain parameters, FSN converges to fractional Gaussian noise, while for others it is a Levy-stable random process. The fractal shot-noise-driven Poisson process (FSNDP), formed when FSN becomes the rate function for a second Poisson process, was considered next. The FSNDP is a point process which has a power spectral density inversely proportional to frequency raised to an arbitrary power (between zero and unity) for certain ranges of parameters. Also developed, were two fractal renewal processes with power spectral densities similar to that of the FSNDP: a standard renewal process with arbitrary power between zero and unity, and a finite-valued, alternating renewal process where the power extends to two. Several applications of these three processes were examined in detail.			
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JSEP FELLOWSHIP: FRACTAL NOISE PROCESSES

FINAL REPORT

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FOR STEVEN B. LOWEN

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Objectives

Major objectives were the definition, development, study, and application of several fractal noise processes.

Accomplishments

Three kinds of fractal noise processes were carefully defined, and their statistics exhaustively detailed. Numerous examples were considered.

Publications

- [1] S. B. Lowen and M. C. Teich, "Power-Law Shot Noise," *IEEE Trans. Inform. Theory* **36**, 1302-1318 (1990).
- [2] S. B. Lowen and M. C. Teich, "Doubly Stochastic Poisson Point Process Driven by Fractal-Shot-Noise," *Phys. Rev. A* **43**, 4192-4215 (1991).
- [3] S. B. Lowen and M. C. Teich, "Fractal Renewal Processes as a Model of Charge Transport in Amorphous Semiconductors," *Phys. Rev. B* **46**, 1816-1819 (1992).
- [4] S. B. Lowen and M. C. Teich, "Fractal Renewal Processes Generate 1/f Noise," *Phys. Rev. E* **47**, 992-1001 (1993).
- [5] S. B. Lowen and M. C. Teich, "Fractal Renewal Processes," *IEEE Trans. Inform. Theory* **39**, (Sept. 1993), in press.

Personnel

Steven Bradley Lowen received his Ph. D. degree in electrical engineering, in May, 1992. His thesis title was "Fractal Stochastic Processes." He is now an Associate Research Scientist with the Columbia University Department of

Electrical Engineering. Malvin C. Teich is Professor of Engineering Science in the Departments of Electrical Engineering and Applied Physics at Columbia University.

Technical Progress

They explored the behavior of fractal shot noise, for which the associated impulse response functions assume a decaying power-law form [1]. Fractal shot noise is a stationary continuous-time process that is fundamentally different from fractional Brownian motion. They obtained expressions for the moments, moment generating functions, amplitude probability density functions, autocorrelation functions, and power spectral densities for a variety of parameters of the process. For certain parameters the power spectral density exhibits $1/f$ -type behavior over a substantial range of frequencies, so that the process serves as a source of $1/f^\alpha$ shot noise for α in the range $0 < \alpha < 2$. For these parameters they presented the first-order amplitude probability density function. For other parameters the amplitude probability density function is a Lévy-stable random variable with dimension less than unity. This process then behaves as a fractal shot noise that does *not* converge to a Gaussian amplitude distribution as the driving rate increases without limit. They considered several physical processes that are well described by fractal shot noise in certain domains: $1/f$ shot noise, Cherenkov radiation from a random stream of charged particles, diffusion of randomly injected concentration packets, the electric field at the growing edge of a quantum wire, and the mass distribution of solid-particle aggregates.

Fractal shot noise may serve as the rate of a second Poisson process, since it is nonnegative by construction: the result is the fractal-shot-noise

driven doubly stochastic Poisson point process or FSNDP [2]. They explored the behavior of the FSNDP, for which the associated impulse response functions assume a decaying power-law form. For a variety of parameters of the process, they obtained expressions for the count number distribution and moments, Fano factor, normalized coincidence rate, power spectral density, and time probability densities. A number of these measures exhibit power-law dependencies, indicating fractal behavior. For certain parameters the power spectral density exhibits $1/f$ -type behavior over a substantial range of frequencies, so that the process serves as a $1/f^\alpha$ point process for α in the range $0 < \alpha < 2$. They considered two physical processes that are well described by FSNDP: Cherenkov radiation from a random stream of charged particles, and diffusion of randomly injected concentration packets.

$1/f^D$ noise occurs in an impressive variety of physical systems, and numerous complex theories have been proposed to explain it. In addition to the FSNDP, they constructed two relatively simple renewal processes whose power spectral densities vary as $1/f^D$: 1) a standard renewal point process, with $0 < D < 1$; and 2) a finite-valued alternating renewal process, with $0 < D < 2$ [3-5]. The resulting event number statistics, coincidence rates, minimal coverings, and autocorrelation functions are shown also to follow power-law forms. These fractal characteristics derive from interevent-time probability density functions which themselves decay in a power-law fashion. A number of applications were considered: trapping and charge transport in amorphous semiconductors [3, 7], electronic burst noise, movement in systems with fractal boundaries, the digital generation of $1/f^D$ noise, and ionic currents in cell membranes.